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MODIFICATION OF A 14MM ASPHALT CONCRETE SURFACING USING RAP AND WASTE HDPE PLASTIC

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ABSTRACT: This paper reports the findings of a laboratory investigation to assess the use of waste HDPE plastic and RAP to improve the performance of a 14mm asphalt concrete surfacing. Waste HDPE plastic obtained from plastic milk cartons was blended with 60/70 penetration grade bitumen and its addition evaluated using the Softening Point test and modified Penetration test at 25°C, 30°C, 35°C and 40°C. This found the addition of waste HDPE plastic to increase softening point and lower penetration value. Deformation and fatigue testing of a 14mm asphalt concrete mix surfacing mix incorporating a blend of waste HDPE plastic and RAP was carried out at a range of test temperatures. This found that modification using waste HDPE plastic and RAP improved both deformation and fatigue properties. The laboratory investigation has shown that the use of waste HDPE plastic derived from milk containers combined with RAP could improve the performance of asphalt concrete subjected to heavy trafficking at higher ambient temperatures.

KEYWORDS: Waste plastic, HDPE, modified bitumen, asphalt concrete, fatigue, deformation

1. INTRODUCTION

Asphalt concrete is probably the most common type of wearing course mix used around the world. However, this material can suffer cracking and permanent deformation problems due to climatic and trafficking factors. A solution to this is the use of modified bitumen. However, many countries can either not afford this luxury or have been looking at alternative approaches. This paper is based on research by Aschuri [1] that investigated the combined use of two quite different waste streams i.e. recycled asphalt plannings (RAP) and plastic derived from plastic drinks containers. RAP has been recycled for many years and its effect on asphalt properties well known. Waste plastic from drinks containers is a problem in both developed and developing countries. Its use in road construction is less well known. The RAP was selected to modify the asphalt mix with the HDPE plastic selected to modify the bitumen.

2. REVIEW OF RELEVANT LITERATURE

The two waste materials assessed were RAP and HDPE plastic. Much has been written about recycled asphalt pavement (RAP) and polymer modification of bitumen. It is created when asphalt pavements reach the end of their service live. In Europe and America, the use of RAP in asphalt mixes has been common practice in the construction of new and reconstruction of old hot mix asphalt (HMA) pavements for many years [2, 3]. However, the use of RAP in developing countries is still not common due to lack of knowledge, research and appropriate specifications. In contrast, about 10 million tonnes of old asphalt is removed each year in the UK with 7 million tonnes reused as RAP.

The binder has an important role to play in the performance of an asphalt mix, particularly its mechanical properties. The behavior of bitumen may be improved by the use of modifiers or additives due to reasons such as increased demand on the road pavement, for use in regions with extreme climatic conditions, environmental and economic reasons [4]. When modifiers are blended or added to bitumen, the properties of the modified bitumen depend on the modifiers properties, the bitumen characteristics, mixing conditions and compatibility of the modifier with the bitumen.

There are many different types of modifier available. The waste HDPE plastic reported in this investigation is a type of polymer. A polymer usually influences the binder characteristics by dissolving into certain component fractions and physically dispersed into the bitumen with long chain polymer molecules creating an inter-connecting matrix of polymer throughout the bitumen. The addition of polymers such as SBS, EVA, LDPE, HDPE and EMA has been found by many researchers to affect the rheological properties of bitumen-polymer blends [5, 6].

These investigations have reported improvement of mix characteristics such as reduced temperature susceptibility, increased elastic recovery at high temperature, reduced complex and creep stiffness at low temperatures, improvement in mix stability, increased resistance to deformation at high temperature and increased resistance to low temperature cracking. However, it should be noted that simply adding polymer to bitumen does not guarantee enhanced mechanical performance of the asphalt mixture [7].

A number of studies have reported the use of recycled plastic, mainly polythene in the manufacture of polymer modified bitumen. Zoorob and Suparma [8] reported that recycled plastics composed predominantly of polypropylene (PP) and low-density polyethylene (LDPE) can be incorporated into conventional asphalt road surfacing mixtures. These mixes containing recycled plastics were reported to have greater durability and fatigue life compared to conventional mixes. Panda and Mazumdar [9] investigated the use of LDPE obtained from reclaimed polyethylene bags in asphalt concrete mixes. The reclaimed LDPE was blended with conventional bitumen and found to increase Marshall stability, tensile strength, fatigue life and resilient modulus.

The use of waste high-density polyethylene (HDPE) as a bitumen modifier in asphalt concrete was investigated by Hinislioglu and Agar [10]. Their results showed that 4% waste HDPE blended in the bitumen improved resistance to permanent deformation. Kumaar and Garg [11] assessed the rheological properties of 60/70 and 80/100pen pen bitumen modified with shredded plastic bag fibres and assessed its effect using the Marshall test.

3. BITUMEN MODIFICATION USING WASTE HDPE PLASTIC

The bitumen used was a UK 60/70 penetration grade. The bitumen modifier was waste HDPE plastic derived from milk cartons. This was collected from household waste and cut into small pieces approximately 2 x 2 mm in size. The thickness, density, melting point, tensile strength and elongation at break of the waste HDPE plastic was found to be 0.5mm, 0.94 – 0.97gm/cc, 120 – 130^{o}C, 31.35MPa and 100% respectively. Bitumen / waste HDPE plastic blends were prepared ranging from 0.75 to 3% by weight of bitumen.

The effect of modification was assessed using the softening point in accordance with BS EN 1427, 2007 [12] and penetration test in accordance with BS EN 1426, 2007 [13]. The penetration test was carried out at 25, 30, 35 and 40^{o}C. Temperature susceptibility was based on Penetration Index (PI) value.

A summary of the penetration and softening point data for the waste HDPE plastic / 60/70 pen blends is shown in Table 1. Penetration value of both the unmodified and modified bitumen / waste blends increased as test temperature increased. The penetration value was found to decrease with increasing modifier content. Increasing the plastic content increased softening point.

Both the penetration and softening point data show that the use of bitumen modified with waste HDPE plastic could improve binder properties in a high temperature climate. Penetration Index (PI) was used to evaluate the temperature susceptibility of each bitumen / waste blend. The PI of the waste HDPE plastic / bitumen blends was found to increase as the percentage of waste HDPE plastic content increased for the range used. This suggests that modification using waste HDPE plastic may have a beneficial effect on temperature susceptibility giving higher stiffness at higher service temperatures compared to virgin bitumen.

Table 1. Penetration and softening point data for waste HDPE plastic bitumen blends

	Waste plastic HDPE bitumen blend			
Penetration (dmm)	0%	0.75%	1.5%	3%
at 25^{o}C, 100g, 5s	78	72	66	55
at 30^{o}C, 100g, 5s	149	122	103	85
at 35^{o}C, 100g, 5s	239	206	176	133
at 40^{o}C, 100g, 5s	350	319	285	223
Softening Point (°C)	45	47	48.5	54

The bitumen stiffness modulus (S_b) was determined using the Van der Poel nomograph [14]. This found that bitumen stiffness modulus increased with increasing modifier content. The waste HDPE plastic / bitumen blends had a significant increase in the slope of the stiffness modulus v. modifier content plot i.e. a small addition of waste HDPE plastic into the bitumen will cause a significant increase in stiffness modulus. Two indicators were used to determine the optimum modifier type i.e. temperature susceptibility and stiffness at elevated temperatures. Based on this 1.5% waste HDPE plastic modification was chosen for all subsequent AC mix investigations.

4. INVESTIGATION OF HDPE AND RAP MODIFIED AC MIX PROPERTIES

The AC mix used was a 14mm surfacing course. The aggregate used in the mix was crushed Palaeogene olivine rich basalt from Northern Ireland. This had a relative density of 2.97, water absorption of 1.22%, Los Angeles of 19%, wet micro-Deval of 24 and polished stone value of 58. The filler used was limestone. The investigation focused on the use of bitumen modified with waste HDPE plastic and the replacement of virgin aggregate with RAP. Table 2 summarises the four mix compositions evaluated and the reference codes used for each.

Table 2. Test specimen reference details

Mix reference	Mix Composition
ACUM	Virgin aggregate + unmodified bitumen
ACM	Virgin aggregate + waste HDPE modified bitumen
ACR30	Virgin aggregate + 30% RAP + waste HDPE modified bitumen
ACR60	Virgin aggregate + 60% RAP + waste HDPE modified bitumen

The Marshall mix design procedure for heavy traffic was used to determine the optimum unmodified bitumen content for the AC grading. This found the optimum unmodified bitumen content to be 6%. The laboratory investigation of mix properties was assessed using Indirect Tensile Stiffness Modulus in accordance with BS EN 12697-26:2004 [15], Repeated Load Axial Test in accordance with BS DD 226 [16], Indirect Tensile Fatigue Test in accordance with BS EN 12697-24:2004 [17] and the British wheel tracking test in accordance with BS EN 12697-22:2003 [18].

3.1. Mix stiffness

A summary of ITSM data for the four AC mix compositions tested at 20, 30 and 40^{0}C is shown in Figure 1. As expected, ITSM was found to decrease with test temperature and increase with increasing RAP content. Mixes made with modified bitumen and RAP had the greatest stiffness modulus suggesting better load spreading ability at higher temperatures.

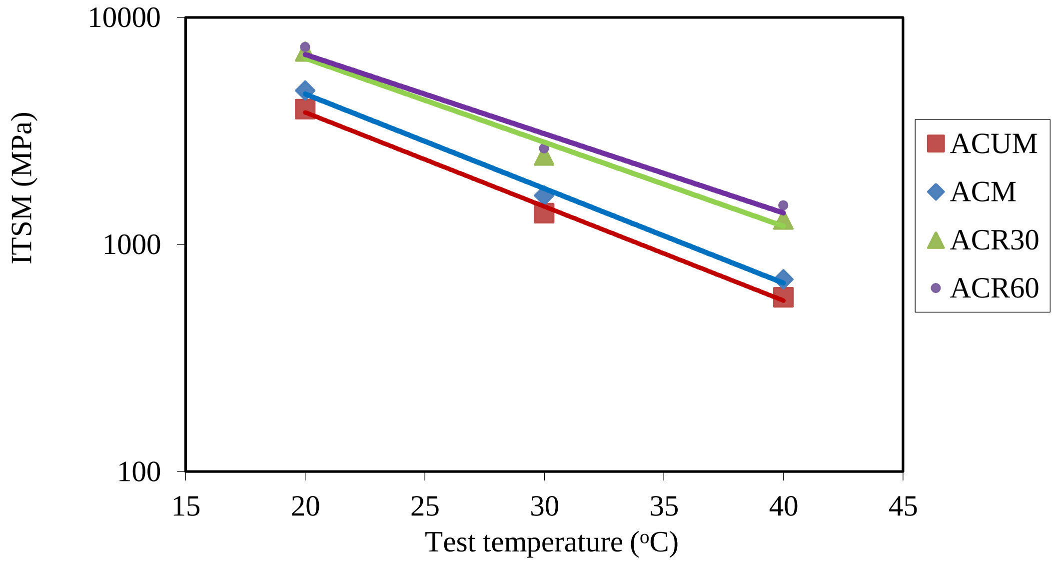

Figure 1 Effect of test temperature on Indirect Tensile Stiffness Modulus

3.2. Permanent deformation

Two different types of test methodology were used to assess resistance to permanent deformation i.e. the British wheel tracking test and the Repeated Load Axial Test (RLAT). The wheel tracking test assessed gyratory compacted [19] 150mm diameter x 50mm thick test specimens at 30, 40 and 60°C. The RLAT test assessed 100mm diameter x 63.5mm thick Marshall compacted specimens [20] at 20, 30 and 40°C.

It was found that deformation was greatest at the beginning of each test and then became linear after a certain number of wheel-passes. The amount of deformation due to initial consolidation or densification was achieved faster as the test temperature increased. The modified HDPE bitumen / RAP mixes had lower rut depths for all of the test temperatures assessed compared to the control mix made with unmodified bitumen. This was due to their greater stiffness and improved shear resistance.

The mixes containing modified HDPE bitumen and RAP had better permanent deformation resistance at higher test temperatures. The ACR30 and ACR60 mixes had reduced rut depths of 45 and 54% respectively compared to the unmodified control mix. This is most likely due to the combined effect of the oxidised binder in the RAP and the waste plastic producing a stiffer mixture which resists rutting.

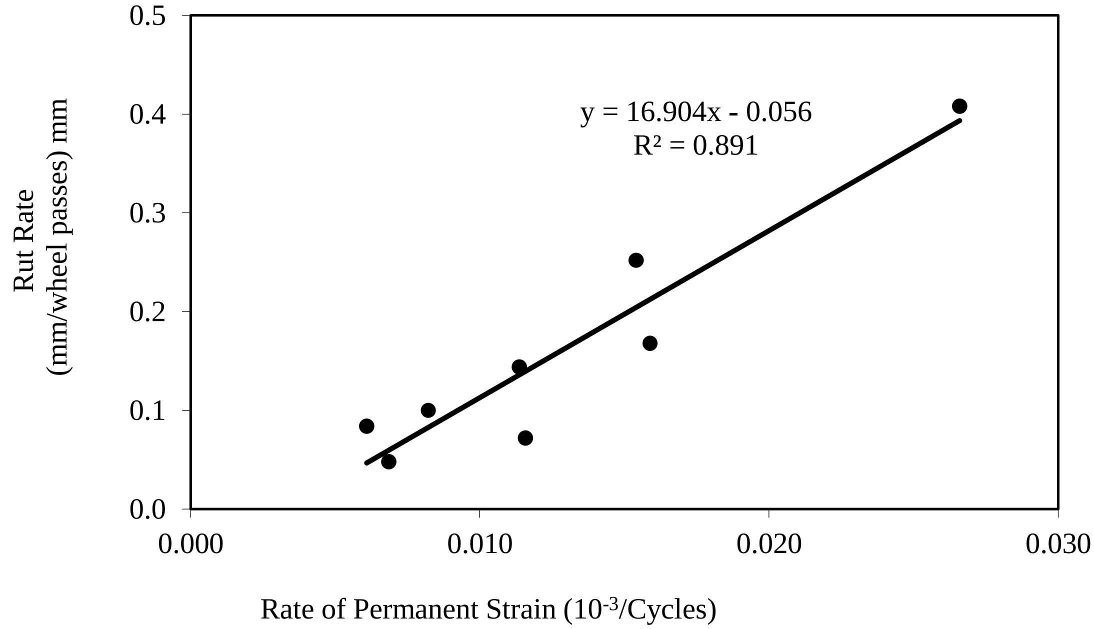

Figure 2 Rut Rate v. Rate of Permanent Strain

Rut Rate from the wheel tracking test was calculated from the standard method and Strain Rate from the RLAT determined by averaging strain rate in the linear phase [21]. Figure 2 plots Rut Rate against Permanent Strain Rate and shows a R^2 value of 0.891. This trend agrees with a previous work by Zhang et. al. [22]. Table 3 shows a ranking for the four AC mix compositions. Both test methods, one fundamental the other simulative, rank the mixes in a similar order with those made with both the modified HDPE bitumen and RAP having better deformation resistance compared to the unmodified control mix.

Table 3. Ranking of permanent deformation test data

Test temperature (°C)	Mix Code	RLAT test			Wheel track test		
		Permanent Strain	Strain Rate	Ranking	Rut Depth	Rut Rate	Ranking
20	ACUM	14.374	0.011	4	-	-	-
	ACM	12.197	0.010	3	-	-	-
	ACR30	7.711	0.006	2	-	-	-
	ACR60	6.430	0.005	1	-	-	-
30	ACUM	17.920	0.015	4	0.81	0.252	4
	ACM	13.223	0.012	3	0.46	0.072	3
	ACR30	7.985	0.007	2	0.42	0.048	2
	ACR60	7.001	0.006	1	0.26	0.084	1
40	ACUM	25.776	0.027	4	1.21	0.408	4
	ACM	15.650	0.016	3	0.88	0.168	3
	ACR30	11.226	0.011	2	0.80	0.144	2
	ACR60	8.389	0.008	1	0.72	0.100	1
60	ACUM	-	-	-	5.03	2.148	4
	ACM	-	-	-	2.2	0.852	3
	ACR30	-	-	-	1.22	0.528	2
	ACR60	-	-	-	1.02	0.518	1

3.3 Fatigue resistance

Marshall compaction with 50 blows each side was used to prepare 100mm diameter test specimens. The test specimens were cut to 40mm thickness for Indirect Tensile Fatigue Testing (ITFT) using the Nottingham Asphalt Tester. ITFT testing was carried out under controlled stress conditions of 400 to 550kPa; 300 to 500kPa and 200 to 350kPa for test temperatures of 20; 30 and 40°C respectively. Visual examination of tested specimens found that 80% of the test specimens containing virgin aggregate showed ideal failure at lower test temperatures and became double split at higher test temperatures. About 75% of the RAP test specimens had a single split at all test temperatures.

The addition of waste HDPE plastic in the bitumen had a beneficial effect on fatigue life at a tensile strain of 100 micro-strains (100×10^{-6}). Compared to the unmodified control mix, the percentage increase in fatigue life for waste HDPE plastic modified mixtures was 17%, 44% and 91% when tested at 20, 30 and 40°C respectively. However, mixes containing both modified bitumen and RAP had lower fatigue life than the control mix. Temperature was found to have a significant effect on fatigue performance i.e. it was better at higher temperatures. This is probably due the higher temperatures causing the mixture to be become softer, decreasing its stiffness thereby absorbing the dynamic loading resulting in delayed crack initiation.

This had been investigated by Huang [23] who found that increased temperature had a beneficial effect on the initial tensile strain fatigue life relationship. This agrees with Choi et. al. [24] who compared fatigue characteristics at different test temperatures using the Two-Point Trapezoidal Test, the Uniaxial Test and a Beam on Elastic Foundation under a Moving Wheel Load.

Table 4 Correlation analysis relating bitumen properties and mix fatigue

Regression equation	R^2
$N_f = 163.56\ (Pen)^{1.659}$	0.875
$N_f = 327099\ (S_b)^{-0.534}$	0.979
$Nf = 1E{+}12(S_m)^{-2.091}$	0.849

Table 4 summarises correlation analysis relating bitumen properties and mix fatigue where N_f= Load cycles at ε_t 100×10^{-6} , Pen = Penetration (mm), Sb = Bitumen Stiffness Modulus (MPa) and S_m= Mix stiffness modulus (MPa). Penetration and stiffness was found to correlate in opposite ways i.e. increasing penetration relates to increasing fatigue life whereas increasing bitumen stiffness relates to decreasing fatigue life. Correlation of mix stiffness modulus with number of load cycles to reach a tensile strain (ε_t) of 100×10^{-6} found a negative trend.

3.4. Air Void content

The relationship between AC mix Air Void content (Va) and fatigue life in terms of number of load cycles to reach a tensile strain (ε_t) of 100×10^{-6} at test temperatures of 20, 30 and 40°C was investigated. The regression analysis is summarized in Table 5. A similar trend was found for the three temperatures i.e. fatigue life decreases with increasing Air Void content (Va) in the mix. Increased test temperature was found to influence the number of load cycles to failure. These findings have important implications for quality control as higher air void contents can significantly reduce fatigue life.

Table 5. Regression Analysis for fatigue life as a function of air void content

Temperature (°C)	Regression Equation	R^2
20	$N_f = 47213215(Va)^{-4.216}$	0.910
30	$N_f = 21089348(Va)^{-2.797}$	0.845
40	$N_f = 2908297630(Va)^{-4.709}$	0.843

3.4 Mix Durability

Mix durability was determined in terms of moisture sensitivity and disintegration using three methods i.e. Retained Marshall Stability, Retained Indirect Tensile Stiffness Modulus and Cantabro Particle Loss Index in accordance with BS EN 12697-17:2004 [25]. It was found that the waste HDPE modified bitumen and RAP mixes were less susceptible to moisture than the unmodified control mix. This finding was found for both Retained Marshall Stability and Retained ITSM test methods. The higher retained values are due to the waste HDPE plastic modification which increased adhesion strength between the aggregate and bitumen binder. The 30% RAP mix had the best retained properties.

Table 6. Regression analysis relating Particle Loss Index with voids and mix Stiffness Modulus

Regression Equation	R^2
$PLI = 1.492\ (Va) – 3.729$	$R^2 = 0.904$
$PLI = 0.0017\ (S_m) – 4.4$	$R^2 = 0.834$

Cantabro Particle Loss Index (PLI) was used to assess resistance to disintegration or particle loss. Table 6 shows the relationships between PLI, voids and mix Stiffness Modulus. All mixes had low particle loss with the waste HDPE plastic / bitumen blend mixes having the lowest amount of particle loss. The slightly higher values for the RAP mixes suggest that its addition is detrimental to a small degree. Air void content affects mix durability performance [26]. PLI was found to decrease with increasing Air Void Content in the mix. Although the amount of particle loss is small the results show that air void content is an important property for quality control. PLI was found to be influenced by a small amount by mix Stiffness Modulus. The low PLI values suggest that the mixes were able to absorb the impact and abrasion forces during testing in the Los Angeles drum.

Table 7 summaries the relationships between Cantabro PLI and fatigue life in terms of number of load cycles to reach a tensile strain (ε_t) of $100x10^{-6}$ at test temperatures of 20, 30 and 40°C. Fatigue life was found to decrease as PLI increased. Test temperature influenced the position of the fatigue line. The data suggests that a mixture with a lower fatigue life will also suffer from more disintegration. The best-fit equations given in Table 7 suggest that the simple Cantabro test may be used to predict fatigue performance.

Table 7. Summary of regression analysis for fatigue life as a function of Cantabro PLI

Temperature (^{o}C)	Regression Equation	R^2
20	$N_f = 4.335 \text{ x } 10^7\ (PLI)^{-2.676}$	0.993
30	$N_f = 1.726 \text{ x } 10^6\ (PLI)^{-1.587}$	0.992
40	$N_f = 9.032 \text{ x } 10^5\ (PLI)^{-2.271}$	0.964

4. SELECTION OF AN OPTIMIZED MIX

An optimized mix was determined by ranking all of the test methods used i.e. in terms of mix stiffness, resistance to permanent deformation, resistance to fatigue cracking, moisture susceptibility and resistance to disintegration. Table 8 shows the completed ranking with a score of 1 allocated to the best mix and 4 to the worst depending on each test method. This ranking methodology found the optimum mix to be ACR30 i.e. AC made with bitumen containing 1.5% waste HDPE plastic and 30% RAP. The poorest performing was the standard unmodified control mix.

Table 8. Ranking of data to determine optimum mix selection

Property / test method	Mix Composition			
	ACUM	ACM	ACR30	ACR60
Mix Stiffness				
ITSM at 40°C (MPa)	586	701	1290	1487
Ranking	*4*	*3*	*2*	*1*
Permanent Deformation				
Rut depth at 60°C (mm) RLAT at 40°C ($x10^{-3}$)	5.03 25.776	2.2 15.650	1.22 11.226	1.02 8.389
Ranking	*4 + 4*	*3 + 3*	*2 + 2*	*1 + 1*
Fatigue resistance				
ITFT at 40°C ($x10^{-6}$)	2.157	4.137	0.321	1.078
Ranking	*2*	*1*	*3*	*4*
Moisture Susceptibility				
Retained Marshall Stability (%) (60°C for 1 day) Retained ITSM (%) (25°C for 28 days)	83.5 47.3	90.4 57.1	95.3 65.4	90.0 58.1
Ranking	*4 + 4*	*2 + 3*	*1 + 1*	*3 + 2*
Disintegration				
Cantabro Loss (%)	3.3	2.3	6.5	9.1
Ranking	*2*	*1*	*3*	*4*
Overall ranking	24	16	14	16

5. CONCLUSION

An investigation of 14mm AC surfacing asphalt mix made with unmodified bitumen, HDPE waste plastic modified bitumen with and without RAP was carried out. Whilst the use of RAP in road construction has been around for many years the use of waste plastic is less well researched. The waste HDPE plastic was obtained from milk cartons and when blended with 60/70 penetration grade bitumen was found to increase softening point and lower penetration value. The optimum amount of waste HDPE plastic was found to be 1.5% by weight of binder. The properties of four mix compositions containing HDPE modified bitumen and RAP was assessed. This found that modification using waste HDPE plastic and RAP improved both deformation and fatigue properties particularly at higher temperatures. It is concluded that the combined use of waste HDPE plastic derived from milk containers and RAP could improve the performance of asphalt concrete subjected to heavy trafficking at higher ambient temperatures.

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